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OFFICE OF THE
CHIEF COUNSEL
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Federal Aviation Administration
Office of the Chief Counsel
Attention: Rules Docket (AGC-200)
Docket No. FAA-1998-4815 - 4
Room 915G
800 Independence Avenue, SW.
Washington, DC 2059 1

DEPARTMENT OF TRANSPORTATION
99 MAR 18 PM 3: 34
DOCKET SECTION

IN QUALIFIED SUPPORT

Dear Sir or Madam:

The Air Line Pilots Association (ALPA), representing the safety interests of 53,000 professional airline pilots flying for 51 airlines in the United States and Canada, has reviewed the notice of proposed rulemaking (NPRM) in the referenced docket. The NPRM proposes modified standards to which engines are certified with respect to their ability to withstand impacts from birds or similar wildlife hazards. We feel the proposed standard is a step in the right direction, but cannot under any circumstances be considered attainment of a goal. As outlined below, the data used in developing the NPRM has been superseded by more accurate values for bird weight, flock size and risk of encounter. These more accurate data, and the reality of ever increasing bird populations, must be part of a program to continuously reevaluate and adjust airworthiness standards. Airport programs are decreasing and formal pilot training in wildlife hazards is nonexistent. Such deficiencies must be corrected and cannot be considered mitigating factors.

FAA Administrator Garvey recently announced that bird strikes cost the U.S. aviation industry $327 million in damage and more than 500,300 hours of downtime each year. Dr. Todd Curtis, limiting his analysis to large jet transports only, in a study for the Bird Strike Committee-USA (enclosed), concludes that there is a 26% chance of a fatal air carrier accident caused by bird strikes by the year 2008. Given this level of damage, risk, and loss, no one can suggest that the current standards are acceptable to the industry and should be retained. ALPA concurs with the effort to improve the standards, but we feel this is only the beginning of what must become a continuous improvement process to ensure an acceptable level of safety for the traveling public as the wildlife hazard increases.

The NPRM states in part an "... assumption that current standards for airport certification will be maintained, that the historical environment will not worsen, and that airport operators and pilots will maintain at least their current awareness of the bird ingestion threat." We feel that none of these assumptions can be considered completely valid.

Many U.S. airport operators with a FAR mandate to have a wildlife mitigation plan do not have the staff or budget to implement an effective plan. FAA certification inspectors have no training in wildlife mitigation plans nor are they required to have any. In addition, airport operators face numerous and diverse challenges to successful implementation of bird mitigation programs from non-aviation interests. In 1997 the U.S. Humane Society obtained a federal restraining order forbidding removal of Canada geese from around the Minneapolis airport area. At Kennedy airport in New York, the USDA shooting program met with large public protest, including assaults against airport personnel. The conditions on which the new standards are based have changed dramatically in the 6-15 year period since most of the data on which the proposals are 'based was collected. ALPA agrees with the FAA when it writes in the NPRM that "Unless the proposal addresses the actual in-service bird ingestion threat, there can be no assurance that future designs would continue to exhibit acceptable capability." Unfortunately the data detailing that actual threat is not presented in this NPRM. Current reporting standards in the U.S. are so lax that FAA Administrator Garvey, in November 1998, called on the industry to "help collect information for a national data base to help control the problem." No mandatory reporting by airport operators or aircraft operators is required and there is no incentive for reporting. The only data available through mandatory collection (from the U.S. Department of Defense and some western European governments) was not used in this NPRM. The NPRM cites two studies which ended in 1984 and 1987 and cannot account for such dramatic increases as the 230% increase in goose strikes to aircraft from 1990- 1998. In a 1998 paper presented to International Bird Strike Committee (enclosed), Dr. Julian Reed of Rolls Royce argued that increasing bird populations will lead to increasing engine failures, although not in direct proportions. The NPRM does not address, nor does it make provision for, bird population growth or an increase in aviation operations. The certification standard should include a formula for increasing engine strength as bird populations and aircraft operations (and therefore risk of ingestion) increase.

The exploding wildlife populations and growth in aviation interests have lead Assistant Secretary of Agriculture Mike Dunn, who is responsible for animal damage control, to say that there has never been ". ..a greater chance for catastrophe than now in the conflict between wildlife and aviation interests." We find it particularly troubling that updated information on wildlife population growth is readily available from credible government studies but has not been incorporated in the development of these new standards. According to the U.S. Department of Agriculture (USDA), "No one has requested data from us (USDA) for the FAA-sponsored ARAC on engine certification." USDA also tells us there has been significant growth in bird populations in the last 10-20 years, and cites the following examples:

- The resident Canada goose population has tripled in the last decade. There are now more than 5 million of these large animals in the U.S.
- The numbers of the Great Lakes cormorant, a 4-lb. bird, increased by a factor of 900 between 1970-1997 due to improvements in the environment.
- The white pelican, a 25-lb. bird, has reached a population level of almost one million and is increasing by 3.1% every year.
- The snow goose population is so large that it is destroying its Canadian habitat.
- Gulls in the Great Lakes region are now so numerous that they have run out of nesting areas and are forced to take over building rooftops as nesting sites.

The certification standard should use the best and most current data available - not only for the number and weight'of birds ingested but for the size of flocks. Recent birdstrike incidents (e.g.

an American MD-80 that left 430 dead starlings on the runway and a USAirways B-737 that left more than 200 dead gulls on the runway) suggest the presumed flock sizes used to develop the NPRM may be unrealistically low. Current science supports that conclusion. Tables in the NPRM which delineate bird weights and numbers are at odds with work done by Dr. John Allan and Richard Budgey of the United Kingdom's Central Science Lab (enclosed). Their 1998 radar analysis of flocks clearly shows that, for a 100 inch engine, expected bird ingestion numbers are: for starlings - 9; for rock doves - 11; for gulls - 4; for Canada geese - 3.

The NPRM states ". ..data analysis has identified specific flocking bird threats up to approximately 8 lb. size (Canada goose)." ALPA questions whether this standard is reflective of the actual threat. Again based on current USDA data, the average resident (non-migratory) Canada goose today typically weighs 12 lb., with the giant species routinely weighing 15 lbs. Since bird weight is critical in testing engine strength, the disparity between actual bird weights and presumed weights must be corrected. The NPRM goes on to say "The FAA recognizes that flocking birds larger than those specified in this proposed rule may be encountered..." We feel this is a significant understatement. Larger birds are being encountered on a daily basis. The FAA document "Wildlife Strikes to Civil Aircraft 199 1- 1997" notes 495 goose strikes between 1991-1997. Since the document states that less than 20% of all strikes are reported we may assume the total goose strikes are actually closer to 2,500 during this period, approximately one per day. The data from this FAA document must be incorporated into the NPRM to reflect current conditions. The hope that ". ..improved airport bird control methods and awareness will further address this very large bird threat.. ." simply ignores reality. No evidence that any improvement is occurring exists. For the last two fiscal years the FAA Technical Center has completely eliminated wildlife studies from its budget. Only after industry protest have the funds been restored and then on a limited basis. During FY99 the FAA has elected to spend only one-quarter of the moneys Congress appropriated for wildlife hazard research on that research. Improved control methods do not exist and will not be developed at current funding levels.

Pilot awareness of this hazard cannot be assumed to be satisfactory. Awareness that wildlife strikes can damage aircraft is different from understanding levels of risk, seasonal and geographic variation of the risk, and consequences presumed by current engine and airframe standards. Some pilots have taken it upon themselves to study the issue, but no U.S. air carrier currently provides training on wildlife hazards. Reliance on such "awareness" to mitigate this public safety threat is unrealistic. The certification standard should abandon the hope that such programs will somehow act as mitigation for engine ingestion events. These vague arguments have no place in a rule ensuring public safety, which should only deal in facts and science.

ALPA supports the idea of aiming the test bird at the engine's most critical point, but we see no justification for the blanket allowance of 10% tolerance for all test parameters. Since engine speed can be closely controlled during the test, a more realistic tolerance for an easily controllable parameter is 1%.

To accommodate commuter and small business jets, "...the [medium bird] criteria was modified to reflect the fact that 250 KIAS was above the normal takeoff and climb speeds for this class of aircraft..." This is no longer true. The fastest growing segment of the airline industry is the regional jet. The CL-65, EMB-145/135, and AVR- 146 all routinely operate at 240-250 KIAS below 10,000 feet. Those speeds are not performance based but are imposed either by ATC restriction or by windshield limitations for birdstrikes. Normal climb speeds for these aircraft are as high as 300 KIAS above 10,000 feet. The number of operations performed by commuter and business jets still is far less than that performed by large transport aircraft. To reduce a certification standard based on performance characteristics of aircraft 20 years ago ignores the realities of the expanding regional jet fleet and is not in consonance with the Secretary of Transportation's vow of "One Level of Safety" for all of U.S. air travel.

Birdstrikes are occurring in greater numbers at altitudes higher than 1500 feet AGL, and speeds at airports are already increasing. Given that, using ". . .the most critical velocity between Vi and 250 KIAS in order to cover the full range of takeoff and climb conditions..." or the compromise value of 'between Vi and the velocity reached at 1500 feet AGL" for the medium bird test is outmoded and obsolete. The FAA Air Traffic Operations Office (ATO-1) has, for more than a year, had a test program in Houston that eliminates the 250 KIAS speed limit below 10,000' and encourages climb speeds between 320-340 KIAS. A Delta B-727 participating in this program encountered snow geese at 7,000' and 280 KIAS and sustained severe damage. In spite of such incidents, the program is slated to expand to Atlanta and Memphis and is being promoted as a capacity enhancement tool and an integral part of the free flight initiative. Clearly, we can expect to see high-speed flight at low altitudes as a routine operation in the near future. The fact that the NPRM is silent on this on-going high-speed flight at low altitude hazard is unacceptable and must be corrected. For aircraft to safely operate in the future air traffic environment, it is clear that engine robustness must be increased to cope with the threats we know will exist.

For the large bird test, the NPRM proposes a 200 knot speed based on the premise that conducting the test at 250 knots *would **likely*** result in a relatively low blade impact vector, resulting in less than maximum bird impact forces on the blades (emphasis added). ALPA questions whether this is a fact-based conclusion or an unproved assumption. If a mass strikes an object at a speed, there is a given force. If another collision occurs with the conditions held constant except for increased speed, the force increases. If there is an element of the dynamics of the collision that serves to reduce that force, it needs to be very clearly spelled out.

We note the absence of harmonized rulemaking in regard to retention of the 4-lb. bird test. The JAA assertion that this difference leaves a void in the testing regimen has merit. To ensure the battery of tests accurately captures the range of threats and to continue in the pursuit of fully harmonized airworthiness codes, FAA and JAA should resolve this difference.

ALPA appreciates the opportunity to comment on this proposal. Although we feel the proposed standard would be an improvement over current standards, the effort falls short of establishing engine criteria that reflect the current and future picture of wildlife hazards. We urge the FAA to continue to sponsor industry groups and research efforts to improve understanding of the threat and, with that understanding, ways to counter it.

Sincerely,

Paul F Eschenfelder /CB

Paul F. Eschenfelder
Wildlife Hazards Project Team Leader

PE:ak
Enclosures

Understanding and Reducing Bird Hazards to Aircraft

Bird Strike Committee USA

North American Fatal Accident Risk

Risk Assessment Basics

Disclaimer

Home

The following risk assessment shows that in the next 10 years there is about a 25% probability that a large jet transport will be involved in a fatal bird strike related accident in the U.S. or Canada.

Background

Bird strikes to aircraft have been a concern since the first recorded fatal bird strike in 1912. More recently, bird strikes have led to fatal accidents for large military aircraft in both 1995 and 1996 and to a commercial airliner in 1988. Increasing North American populations of birds such as geese and ducks have led to a significant increase in the threat to aircraft, especially in areas on or near airports. The probability of a fatal bird strike accident can be estimated based on the past bird strike record. Specifically, the following analysis will estimate the probability of a fatal accident involving a bird strike to a large jet transport aircraft occurring in the next ten years in the U.S. or Canada.

Risk Assessment Basics

Risk is defined as the combination of a specific hazard and the likelihood of that hazard. The specific hazards in this context are bird strike events that result in:

1. Both fatalities and aircraft hull loss.
2. Aircraft hull loss only, or
3. Other economic losses ($26 million wildlife losses 1993-1995 from FAA reports).

The likelihood of these three hazards can be roughly estimated from the following information:

1. Fatal and non-fatal worldwide hull losses since 1959 (five total, one fatal),
2. Total jet transport flights since 1959 (about 300 million),
3. Estimated U.S. and Canadian large commercial jet transport flights 1999-2008, (80 million),
4. Average load factor of 54% (60% for airliners, 0% for cargo jet transports, 10% cargo flights),
5. Average passenger capacity (130),
6. Probability a passenger dies in a fatal bird strike accident (0.5), and
7. Cost of average jet transport (30 million 1997 dollars).

Assuming that the historical world hull loss rate is roughly current underlying rate in the U.S. and Canada,
P(Hull Loss From a Bird Strike Event) = 5/300M = 1.67 x 10-8
P(Fatal | Hull Loss) = 0.2
P(Fatal Hull Loss Event) = 3.3 x 10-9
P(Fatal Hull Loss Event in U.S. or Canada) = (3.3 x 10-9)(8 x 10+6) = 0.027/yr

Assuming a binomial distribution of events, this would imply that over the next decade,
P(Zero Fatal Hull Losses) = 0.763
P(One Fatal Hull Loss) = 0.209
P(Two Fatal Hull Losses) = 0.026
P(Three Fatal Hull Losses) = 0.001
Estimated Fatal Hull Losses = 0.209 + 2(0.026) + 3(0.001) = 0.263
Note: This last figure means that in the next 10 years there is about a 25% chance of a fatal bird strike accident involving a large jet transport in the U.S. or Canada
Estimated Fatalities = 9.2 = (0.263)(130)(0.54)(0.5)
Estimated Non-Fatal Hull Losses = 1.05 = 4(0.263)

Table 1: Cost In Lives and Property Due to Bird Strikes 1999-2008

Hazard	Estimate	Cost
Lives Lost	9.2	$23 million*
Aircraft Losses	1.3	$39 million
Other Losses	-	$87 million**
Total	-	$149 million

* Assume $2.5 million in liability claims per life lost
** Based on 1993-1995 FAA figures for wildlife losses, may represent only 1/20th of total economic losses
(see Wildlife Strikes to Civil Aircraft in the United States: 1991-1997)

Home

Rolls-Royce

Birdstrike Statistics as a Design Tool

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Abstract-Statistics regarding the aerospace sector are routinely generated by regulatory bodies, engine manufacturers, airframe manufacturers and research organisations. Whilst these statistics are interesting from a background information and setting trends viewpoint, they are seldom used directly in the design process for new components. This paper shows one way in which raw statistics, when coupled with the Monte-Carlo technique, may be used to generate data which is able to directly influence designs. The example chosen for this paper is that of birdstrike resistance of high bypass ratio aircraft engines, although the technique is a generic one.

1.0 Introduction.

Many statistics on birdstrikes are collected and reported at conferences and in the literature but it is generally the case that they are used for background information and for gaining a qualitative appreciation of the problem.

An example of this is the observation that, according to Reference 1, 1 in every 70 birdstrikes on a Boeing 737 engine is by a bird which is heavier than 8lb in mass. This fact is interesting in that it gives an idea of the size and rate of occurrence of a possible threat an engine might be subjected to, and could certainly be used by certifying authorities as supporting evidence to support a certification requirement.

However, it is difficult to see how this information might be used in any more direct way e.g. as a design tool to control the sizing of engine components.

The purpose of this paper then is to demonstrate that with just a few raw statistics used in conjunction with the Monte-Carlo technique, it is possible to generate a ~~powerful~~ design tool. The raw statistics referred to are available from a host offdisparate sources, the following being just a few examples:

I; **FAA** bird ingestion data.
II; Aerospace Industries Association bird ingestion data.
III; Rolls-Royce in-house engine data.
IV; ICAO ingestion speed distribution data.

2.0 The Monte-Carlo Technique.

In order to clarify the way in which the Monte-Carlo technique works, it is necessary to define an event. An event may be defined as a naturally occurring phenomena with a readily quantifiable outcome and several randomly varying input variables upon which the outcome depends.

Impact in its broadest sense lends itself to description in these terms since there is usually only one result of interest, whether or not the target is damaged. There are a number of input variables e.g. speed of impact mass of projectile, strength of target, attitude of target etc.

The Monte-Carlo technique relies upon the fact that it is possible to establish mathematically the effect of any one input on the output and also that the distribution of each input variable is known; i.e. how likely is the projectile to be travelling at a given speed or how heavy the projectile is likely to be.

It is then possible to sample each input distribution in **a** completely random manner in order to define one outcome which can then be assessed against the chosen criteria; e.g. damage or no damage.

If this process is repeated enough times (typically above 1000) then enough data is generated to make a meaningful statistical statement about the likelihood of the outcome failing the criteria; i.e. how likely is it given the distribution of projectile mass, target strength, attitude of target etc that the component will experience damage.

In this way the statistical data may be used in a direct rather than indirect manner.

3.0 Analysing the Engine Ingestion Event.

When an engine ingests a bird, the damage done, and hence its capability to run on and produce power, is dependent on the **values** of **several** input variables. In its simplest form, heavier birds will do more damage. The power level at which the engine is operating at the time of ingestion will also affect the outcome - when the engine rotors are operating at high rotational speeds and producing high thrust on take off, more damage be done than would be the case at low power conditions such as descent and approach. The strike position on the engine will also be important, the fan blade tip tends to be the most vulnerable target area, speed of the aircraft at the time of the ingestion will also affect the resulting damage.

To establish **a** Monte Carlo model of ingestion it must first be understand how these independent variables combine to produce damage on an engine component. For instance, it is easy to appreciate that ½ bird mass x impact velocity squared is the kinetic energy of the bird and that the damage done to a wing or other static component will be **a** function of the impact KE. If a KE criterion can be established by test for the component in question then it will be possible to work through many randomly generated cases of bird mass and velocity to see how many exceed the criterion and will cause failure as a result.

In the same way, using experience validated by test data, it is possible to produce simple impact parameters which characterise the severity of impacts on fan blades, core compressors and engine spinners, these being the exposed areas of the front face of the engine. These simple impact models can then be built into a spreadsheet to form the basis of the statistical analysis.

4.0 Spreadsheet Monte-Carlo Analysis of Ingestion

The manner in which the ingestion problem has been put into a MS/EXCEL spreadsheet is as follows. Four sets of statistics have been used as the base data:

I) An ingestion speed distribution as published in ICAO 1994 and 1995. See Figure 1.

ii) A take-off fan speed distribution. This is typical generic data but could well be applicable for any high bypass large civil engine. See Figure 2.

ill) Strike position distribution. This is easily generated by using area weighting considerations. See Figure 3.

IV) A bird weight distribution as published in FAA surveys on high bypass ratio engines. See Figure 4.

The data are all in the form of cumulative probability (0.0 to 1.O) vs data occurrence curves. intercepting the curve at a chosen probability level implies a certain value of the data.

Using the random number generator in EXCEL it is possible to generate a number between 0 and 1. This is then used to interpolate in a curve to obtain the relevant value. This process is carried out four times to establish the four input variables listed above.'

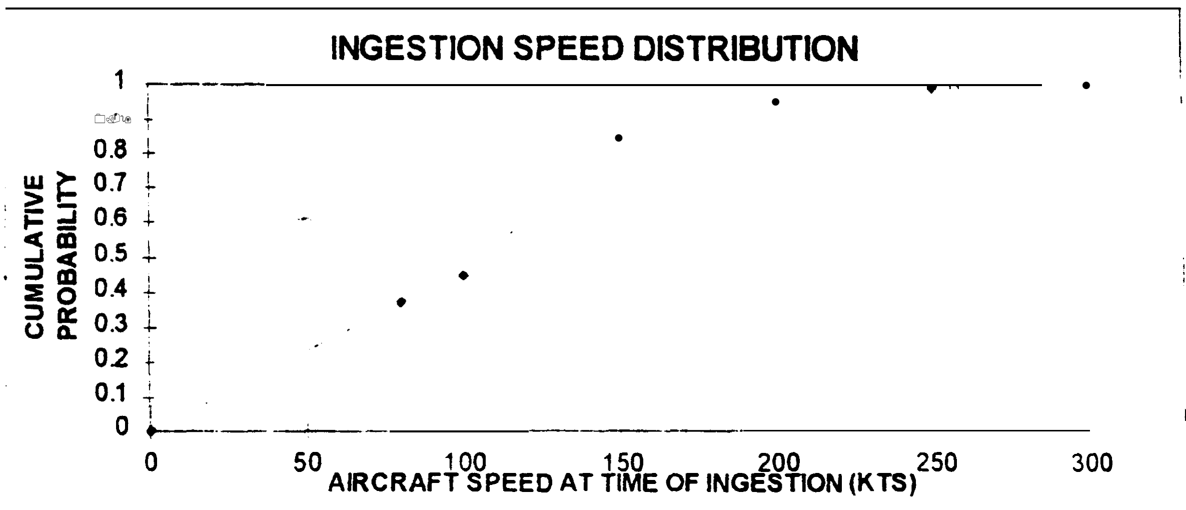

Figure 1 - Ingestion speed distribution

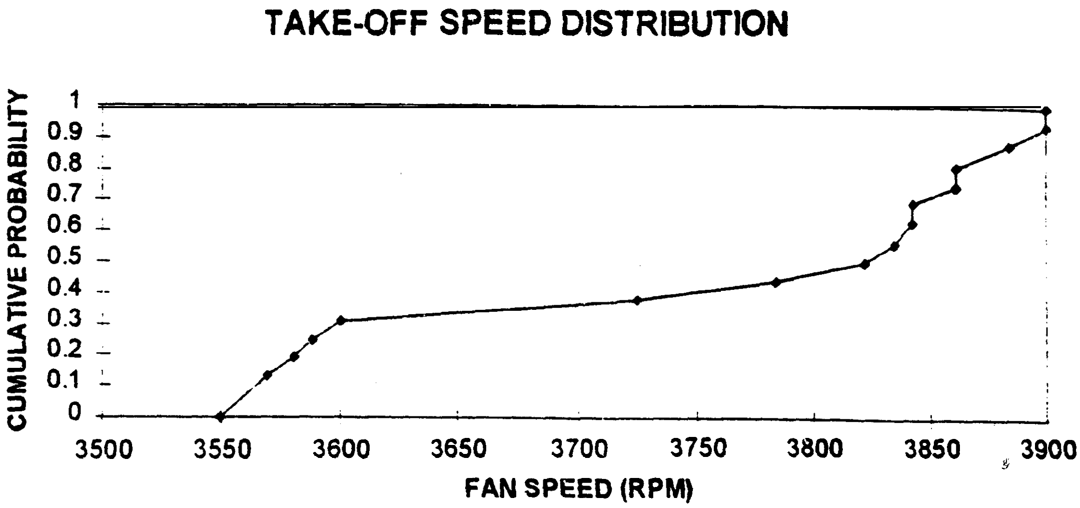

Figure 2 - Typical Take-off Speed Distribution

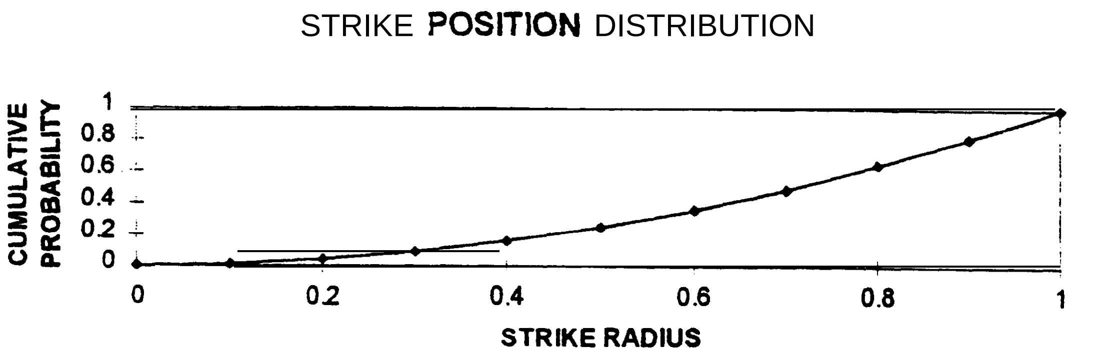

Figure 3 - Strike Position Distribution

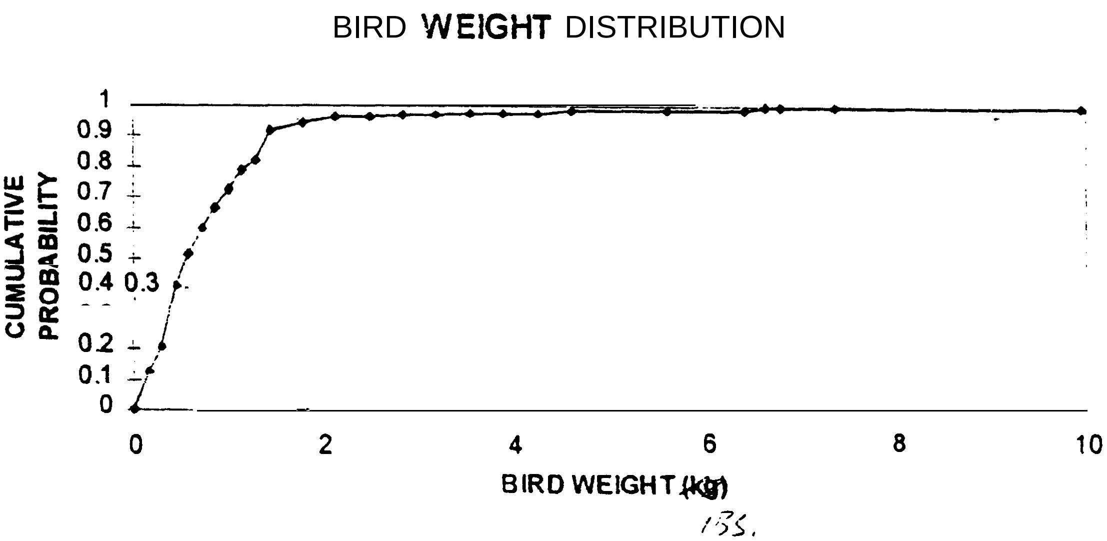

Figure 4 - Bird Weight Distribution

The. strike radius value is then interrogated to establish whether the impact is happening on the spinner, core compressor, bypass area or fan blade tip. According to this interrogation, the appropriate part of the spreadsheet is then invoked to establish whether at this particular strike height, bird mass, bird speed and blade speed the computed impact energy exceeds the predetermined failure criterion which represents the strength of the engine components.

The passes and fails are then recorded as the above process is repeated for 1000 iterations. This leads to the generation of a curve of which Figure 5 is typical. This **charts** an engine failure rate as it develops through the total number of iterations **made.** It can be seen that initially the variation in faiiure rate is high due to the low number of iterations and therefore poor statistics. As the number of iterations completed grows the statistics become of **higher** quality and the variation from the true engine failure rate becomes less.

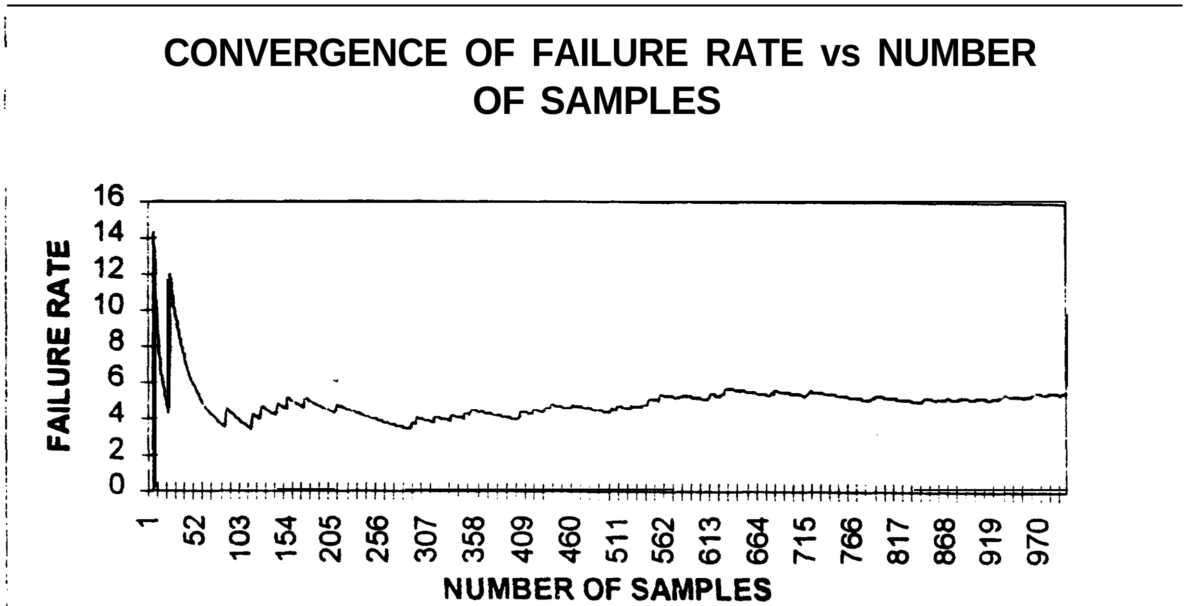

Figure 5 - Convergence of Solution

5.0 Examples of Theoretical Conditions

Clearly a tool of this kind should be calibrated in some way to assess how close to reality it is.

The plot in Figure 6 shows what happens as the engine is made progressively stronger; analagous to certifying the engine at progressively higher bird weights. It may be seen that the failure rate at a 1 .5lb certification is computed to be 12.7%. This compares well to 11% observed on the 1 st FAA survey of large civil engines.'

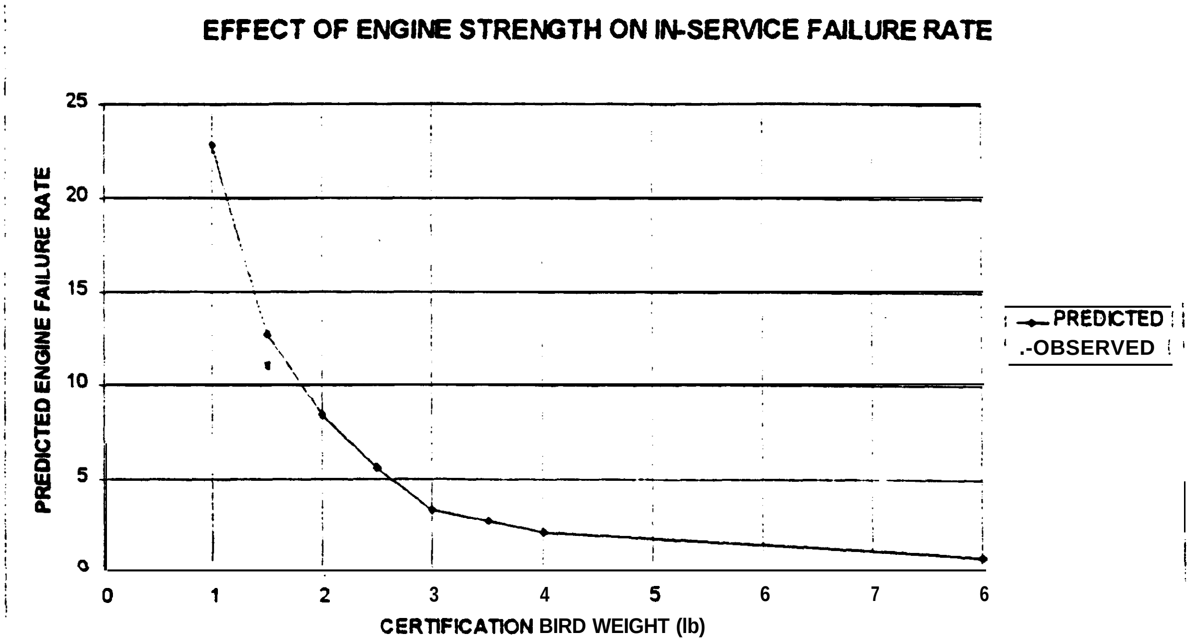

Figure 6 - Effect of Engine strength on In-Service failure Rate

The plot however, also neatly displays the law of diminishing returns; i.e. in order to force the failure rate of the engine down, the bird certification weight (and therefore engine strength and engine mass) has to increase by a correspondingly much larger amount.

The plot in Figure 7 shows what happens to the engine failure rate as the percentage of large (>8lb) birds in the population grows. This is an example of how the method can be used to explore 'what if' questions. In this case, a doubling in the population of large birds does not result in a pro-rata increase in engine failure rate. t a conclusion which could have been-arrived at intuitively and illustrates how an analysis like this can give previously unobtainable insights into the birdstrike problem, give numerical answers to questions and quantify how effective any remedial action might be.

6.0 Conclusions

The techniques employed in this paper are not new, but with the advent of powerful spreadsheet programs such as MS/EXCEL, it is possible to use them to far greater advantage than before.

For the fairly simple example shown in this paper, it has been possible to show how raw statistics **can** be used directly in a design environment and how such an analysis can extend the use of already available statistics.

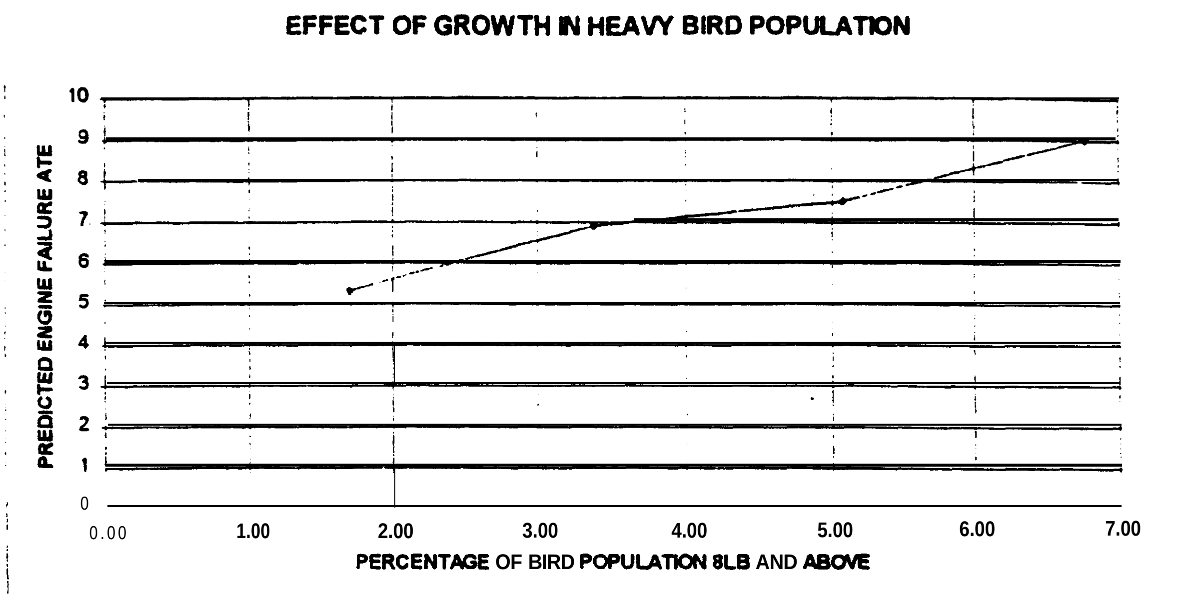

Figure 7 - Effect of growth in Heavy Bird Population

7.0 References

1.0 **Engine Bird Ingestion**. Experience of the **Boeing 737 Aircraft - Expanded Database,** October 1986 to September 1989, FAA Technical Centre.

THREE DIMENSIONAL BIRD FLOCK STRUCTURE AND ITS IMPLICATIONS FOR BIRDSTRIKE TOLERENCE IN AIRCRAFT

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Summary

The number of birds currently used in multiple impact certification is based on data from the historical birdstrike record. As bird populations and engine designs change, new test criteria are periodically required. In order to measure future risks from species rarely struck at present, and confirm the level of risk from species that have been struck frequently, it is necessary to supplement the historical record with direct measurement of the threat posed by flocking birds. We describe a method for filming bird flocks using a stereo pair of video cameras and determining the three dimensional structure of the flock. By modeling the flocks and plotting the path of an aircraft component through them, it is possible to determine the probability of striking a given number of birds and we include some initial results from running the model. These data can then be used by regulators to inform the choice of bird numbers and weights in future certification testing requirements. We also try to describe a relationship between bird flock density and a biometric factor such as wingspan. If this relationship holds as more data are gathered, the model can then be extended to any species of bird.

Key words: Flock density, Certification standards, Mathematical models

Introduction

Before entering service. a new aircraft component such as an engine or windshield must pass stringent airworthiness tests. one of which is its ability to withstand bird impacts. The authorities which formulate these tests recognise that in a collision with a flock of birds, more than one will be struck. so they require components to be tested against a of number birds simultaneously. At present the requirements of the JAA regulation which relates to engine bird ingestions, JAR-E 800, are the ingestion of one or more birds of between 4oz and 1.5lb, depending on engine inlet diameter, after which the engine must continue to produce at least 75% of full power and one 4lb bird, after which the engine may be shut down, but must not fail hazardously.

The number of birds used in these tests is derived from information from previous birdstrikes where the number of birds recovered after an incident or seen by air or ground crew has been recorded. These reports are not always reliable (Allan and Hammershock, 1994). The species and hence weight of the birds involved may not be identified, and the number is often not recorded precisely. Another drawback of tk historical record is that it cannot reflect current or future changes in bird populations. If the species and flocking behaviours commonly encountered in multiple birdstrikes change, such as is the case with the Canada Goose which is rapidly increasing in number (Allan et al. 1995. Seubert 1996), birdstrike testing may not fully represent the threat actually faced by aircraft. By directly measuring bird flock densities and modeling bird flock / aircraft interactions, we can predict the probability of striking given numbers of birds in a flock of any species. The findings from this work can be used to inform the design process when new bird impact regulations are being formulated.

There have been previous attempts to estimate the threat posed by bird flocks through analysing flock structure. Dill and Major (1977) used stereoscopic pairs of photographs to calculate the distance in space between a bird and its nearest neighbour in the flock, known as the "nearest neighbour distance" (NND) and interbird angles. van Tets (1966) and Sugg (1965) used single photographs for two-dimensional estimates of densities of bird flocks in flight. Pomeroy and Hepner (1992) used a perpendicular pair of cameras to find three dimensional **NNDs** but without any particular interest in birdstrikes.

In this study, we have chosen to adapt the method used by Dill and Major and use a stereoscopic camera pair. The other methods described above, while having **some** advantages, are not entirely suitable for assessing the birdstrilce hazard of **flocks.** van Tets' method was simple and could be applied to any photograph but it made the assumptions that a group of birds occupied a spherical airspace of the same diameter as the smallest circle enclosing them on the photograph and that the distance between birds could be estimated by *measuring* their lengths or wingspans on the **photograph.** From a single image there is no way of checking whether either assumption is reasonable. Sugg was only interested a two dimensional analysis of flock **structure** and made the assumption that flocks would be struck head on. Pomeroy and **Hepner** measured three-dimensional data but their equipment had to be set up in a permanent location as they wanted to study turning behaviour in a **flock** of Rock Doves which were trained to fly past the camera.

The major adaptation on the Dill and Major method is the use of video rather than still cameras. This means that the position of birds in a series of video **frames, only 1/24** of a second apart, can be averaged to reduce errors due to camera resolution or incorrect identification of the center of the bird on the video image, etc. A long sequence of video footage can be recorded, capturing a number of flocks as they fly past the cameras.

This method uses the degree of **parallax** shift between the cameras in the stereoscopic pair to measure the distance and angle from camera to object and returns the **three-**dimensional position of each bird in a flock. The flock is modeled on a computer and a series of random trajectories can be projected through it to represent aircraft or aircraft components. The number of birds struck on each pass of a component gives a measure of the threat posed by flocks of each species.

Methods

Field system

A stereo pair of digital video cameras was used to film flocks of a number of bird species in the UK in locations where their behaviour was iikely to be similar to that found on airfields. Species filmed were Starling, Rock Dove (Feral Pigeon), Lapwing, mixed gull flocks and Canada Goose. The cameras were mounted. with identical film planes, at a distance of 2.54m apart on a section of optical beam with a cross-sectional shape that prevented bowing. The beam was mounted on two standard photographic tripods. Provision was made to allow the cameras to be adjusted so that the axes of the lenses were parallel. or so that any degree of divergence from parallel could be measured, by filming a calibration beam with two chequerboard images, also 2.54m apart. The cameras were Pulnix TM-765 black and white digital video cameras with a resolution of 756 by 581 pixels. Lenses of three focal lengths - 28mm. 50mm and 75mm were used. The images were recorded on professional quality U-matic video cassettes using two Sony VO-8800P VCRs that each had a time code unit, one slaved to the other so that frames on both VCRs were recorded at exactly the same time and could be matched for analysis. The images were monitored in the field using a video monitor with an input that could be switched between the two cameras.

The equipment could be transported in a vehicle to suitable field sites. The VCRs and cameras were battery powered and the monitor was powered by a take-off from the vehicle battery. On arrival at the field site, a calibration image was filmed as described above.

Limits of the system

Due to the limits to resolution of the cameras, the maximum distance at which birds can be filmed is about 300m. A calibration trial was conducted which tested both the field and laboratory based systems. The distance to an object placed at 300m, as measured by tape measure. was measured with an error of 2.3% by the system. Errors in X and Y are considerably smaller than the errors in Z. and can be reduced by taking the average position of birds over 10 consecutive video frames.

Conversely, if birds are too close they are only "in frame" in both cameras for a very short time, if flying perpendicular to the mounting beam. In order to obtain 10 frames of film, birds must be visible in both cameras simultaneously for 0.4 seconds.

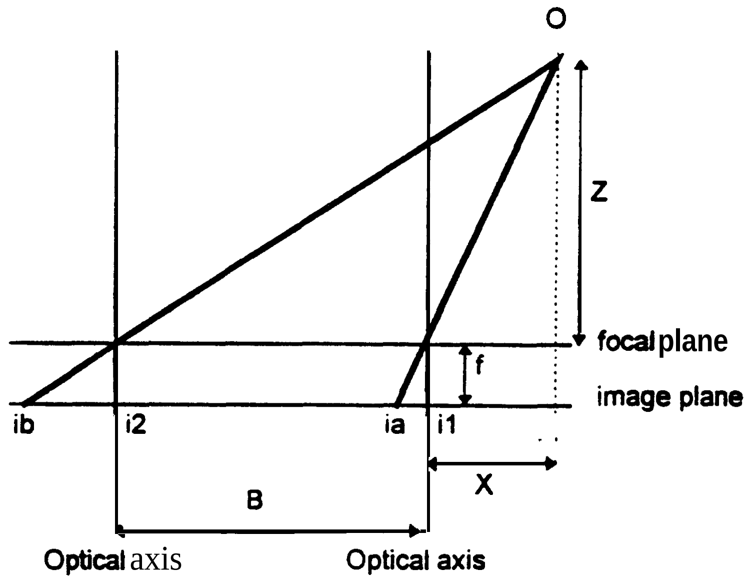
Image analysis

The videos were played back on a Sony VO-9800P video editing suite with a jog/shuttle facility and individual frames were transferred on to a PC using a Snapper video frame grabber extension card and software that also allowed image contrast, brightness, etc to be altered. Matched frames from each video could be identified by comparing time codes. It is essential that the images from each camera are recorded simultaneously to calculate three dimensional positions.

Once stored as computer image files. the X, Y coordinates of individual birds on each image were measured using the object detecting routines available in Optimas, an image analysis software program. It was obviously important that one could identify the same bird in both images of a pair and this was possible using Optimas by placing them side-by-side on the screen. The pairs of XY image coordinates of each bird were exported to spreadsheet software that automatically returned the real-world XYZ coordinates and nearest neighbour distance for each bird.

Geometry

The XYZ coordinates of a bird are derived from stereoscopic pairs of XY coordinates by the method of similar triangles. If the separation of the two cameras. the focal length of the lenses. the total extent of the image and the position of the bird on the image are all known. the position of the bird in space can be deduced. viz:



Where:

0 = object

Z = distance to object along the optical axis of the right hand camera

X = perpendicular horizontal distance to object from optical axis of right hand camera

Y = perpendicular vertical distance to object from optical axis of right hand camera

B = camera separation

f = focal plane to image plane distance = focal length of the lens

ia = image position in right hand camera

ib = image position in left hand camera

From similar triangles:

X = (iai1 z) / f Y = (ydisp z) / f Z = (f B) / (ibi2-iai1)

Where ydisp is the y displacement from the optical axis.

The camera image position is calculated by scaling down the computer image XY coordinates returned by the Optimas image analysis software.

The Model

The modeling process is carried out using spreadsheet software. The XYZ coordinates of the flock are normalised. that is to say the origin of the coordinates system is moved from the camera to a comer of the flock. A set of random trajectories are generated for aircraft components through the flock and the number of strikes in each pass is recorded as a frequency histogram. A broad cross-sectional area can be applied to each trajectory so that for say, a 100 inch diameter engine any birds within 50 inches of the center line of the trajectory will be counted as being struck. More complex shapes such as windshields can also be modeled. The trajectories are limited so that they are never steeper than the maximum climb out angle of an aircraft.

In order to use the model predictively, it would be desirable to relate flock density to a biometric factor such as wingspan. To this end it is convenient to use a single figure to categorise flock structure. One such term is the flock's mean NND, alternatively one could use a term obtained from the histogram described above, such as the mean number of birds struck or the 95th percentile (ie the maximum number of birds struck from all passes through the flock, excluding the most severe 5% of cases). This is a useful term for aero-engineers as it describes the flock in terms of its birdstrike hazard. If the 95th percentile of a species is found to be proportional to its wingspan, it would be possible to predict the birdstrike risk of any species from its wingspan alone. Taking the value of the 95th percentile as the number of birds used in a multiple impact test ensures that the test is stringent enough to describe 95% of likely multiple ingestions. Other values such as the 90th or 99th percentiles could be used if a more or less stringent test were required. One thousand is the recommended number of randomisations for estimating 5% significance (Manly 1991) which is analogous to estimating 95th percentiles, so we model 1,000 passes of a component. If a more extreme percentile figure is required. say 99%, a greater number of passes would be required

Results

Charts 1 to **5** show the positions in three dimensions of birds in an **example** flock of each species.

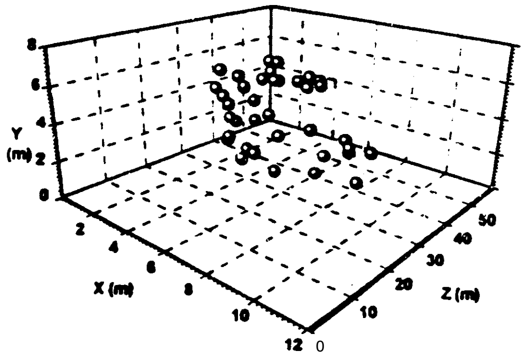


Chart 1. Starling

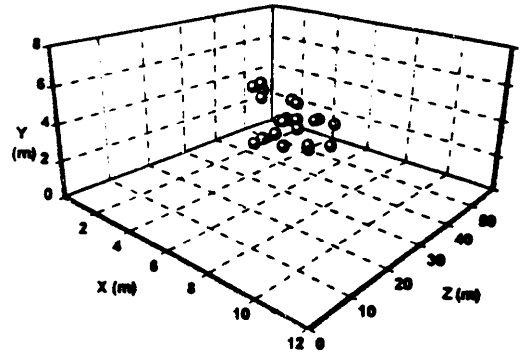


Chart 2. Rock Dove

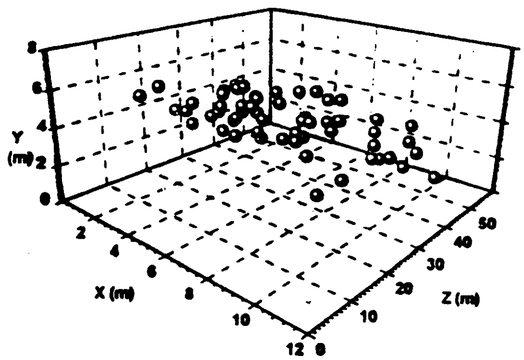


Chart 3. Lapwing

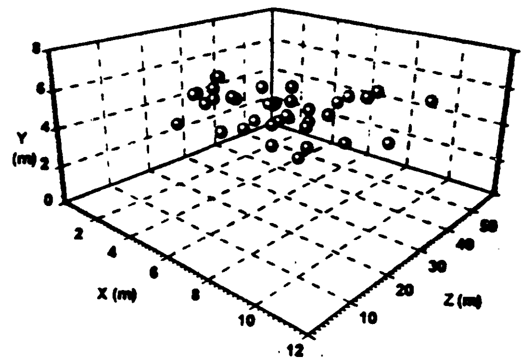


Chart 4. Mixed Gulls

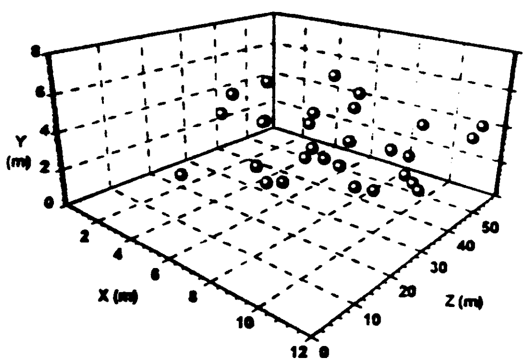
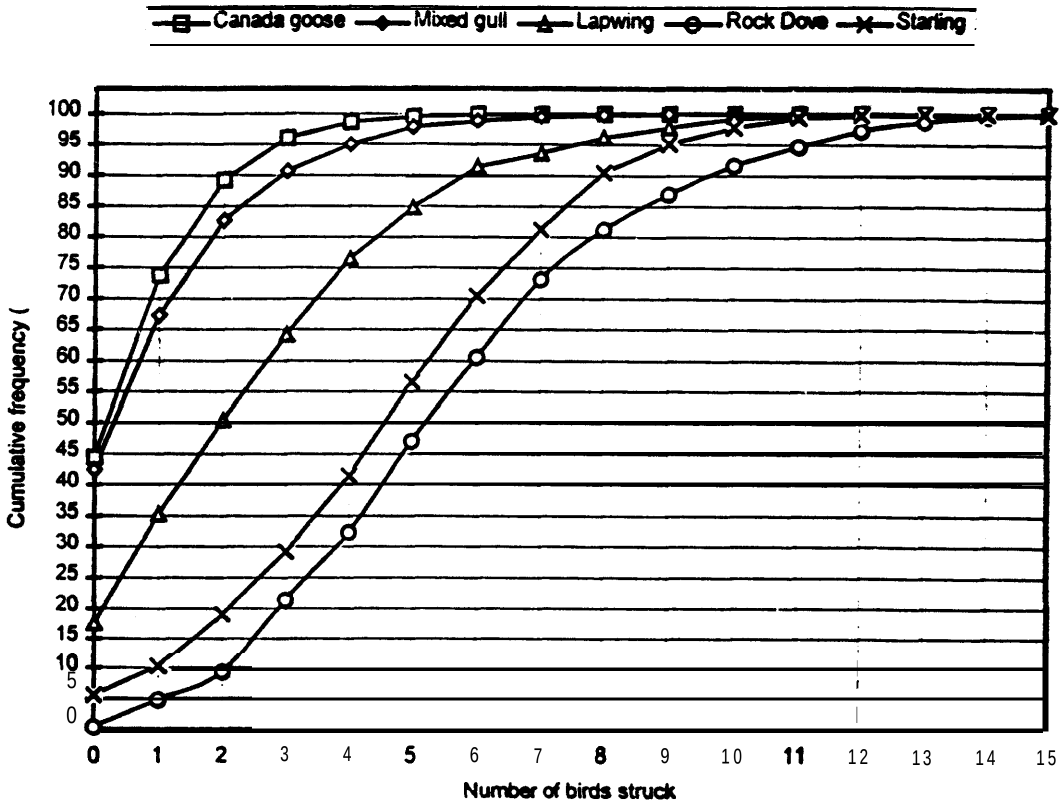


Chart 5. Canada Goose

Chart 6. Results from running the model - the cumulative frequency of striking a given number of birds for 1.000 passes of a 100 inch diameter jet engine through each of the flocks shown in charts 1 to 5.



From this chart it is possible to choose a value of cumulative frequency, say 90% or 95% and investigate the relationship between that value and the wingspan of each species, as shown in charts 7 to 10. Chart 11 shows the relationship between wingspan and NND for the five flocks described here.

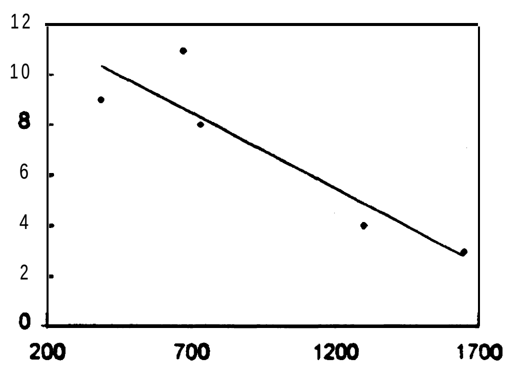


Chart 7. 95th percentile vs Wingspan (mm)

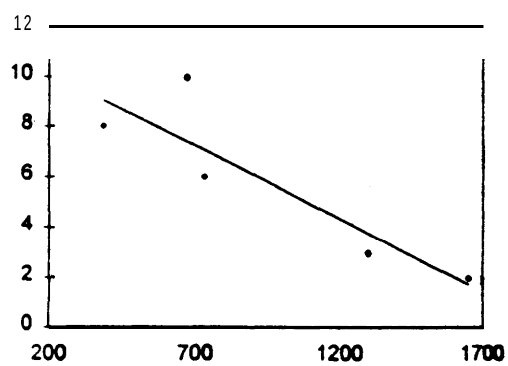


Chart 8. 90th percentile vs Wingspan (mm)

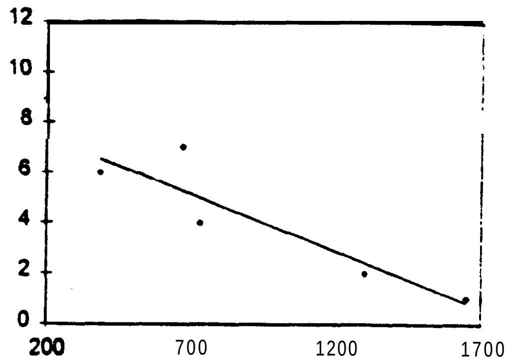


Chart 9. 75th percentile vs Wingspan (mm)

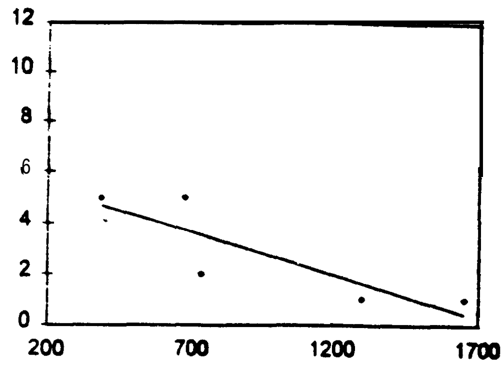


Chart 10. 50th percentile vs Wingspan (mm)

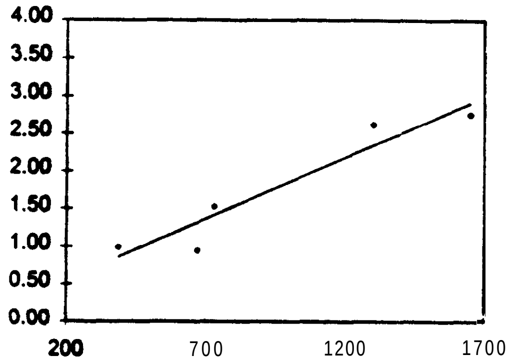


Chart 11. NND (m) vs Wingspan (mm)

Table 1. Details of flocks 1 - 5

	Number of birds in flock*	Mean NND (m)	95%ile from model	wingspan (mm)
Starling	38	0.99	9	387
Rock Dove	21	0.95	11	670
Lapwing	61	1.53	8	730
Mixed Gull	37	2.62	4	1300
Canada Goose	29	2.76	3	1650

*This represents the number of birds visible to both cameras simultaneously, rather than the total number of birds in the flock.

The NNDs we have obtained are similar to those reported by other workers. Pomeroy and Hepner recorded Mean NNDs of about 1.2 meters for Rock Dove and Dill and Major found NNDs of 0.63 meters for Dunlin and 1.33 meters for Starling.

Discussion

From the data presented above. there is an apparent relationship between the wingspan of a flocking bird. its nearest neighbour distance and the number of birds likely to struck by an aircraft encountering a flock of that species. However. these data represent **only** one example flock of each species. Many more **flocks** in a variety of situations must be filmed before these results can be considered significant.

By modeling species which are commonly struck now or which may be a problem in the **future,** we can provide information on the number of birds that an aircraft is likely to encounter during a birdstrike. The international aviation community **can** use these results to inform the design process when new bird impact certification tests are devised. Aero-engineers and regulators can decide how severe they want the tests to be, whether they should represent, say, **90%, 95%,** 99% or even 100% of likely multiple impacts. At each of these levels of severity, the number of birds to be used in impact tests at each test weight can be derived **from** the wingspan of those species which are represented by each weight category.

Even if the relationship between wingspan and flock density that we have suggested does not remain valid as **further** data are collected, we have described a method which can directly measure the birdstrike threat posed by any species of bird; if a test is required that simulates a collision with a particular species or group of species of a particular weight. the number of birds to be used in the test can be obtained by filming and modeling those species.

Validity of the model

If we are to correctly predict the hazards faced by aircraft, we must be sure that the flocks we are modeling are representative of flocks that are likely to be struck throughout the world.

One of the most important factors regulating the number of birds that can be *struck is* the number in the flock. It is particularly important that impacts are modeled with flocks of a size representative of those found on or close to airports. Further fieldwork or literature study will be required to determine these flock sizes. Even if one were unable to **film** flocks of the required sizes. the size of the flock used in the model could be adjusted to this level. However this would be to assume that flocks of different sizes are similar in structure - it is possible that bird separation varies as flock size increases.

The shape of flocks is also important. If flocks tend to extend in **only** one dimension as numbers increase. ie they become "sausage" shaped. then it is unlikely **that** increasing size will affect the birdstrike hazard unless an aircraft were to fly down **the** long axis of the flock If flocks did exhibit this type of overall shape, it may **only** be necessary to obtain data for flocks up to a certain size if the probability of an **aircraft** flying down the long axis of the flock were sufficientiy low.

The structure of bird flocks is of great interest to biologists and several possibilities have been suggested to explain why different flocking strategies are adopted. The 'V' shape typical of long distance migratory goose skeins probably results **from** an attempt to reduce the energy cost of flying (Speakman and Banks. 1998). When transiting short distances, for instance from roosting site to feeding site. geese form much looser, less structured flocks. The structure of flocks found in species such as Starling, Lapwing, etc is probably an anti-predatory adaptation such as is found in many groups of animals (Bertram. 1978). The large number of possible prey to choose **from** is bewildering to a predator and the probability of any individual being caught is reduced when in a group. Birds on the periphery of such flocks are at greater risk of predation and continually try to obtain a better position in the **flock** (Pommery and Heppner, 1992). The structure of this kind of flock may be different when a predator or other threat is actually present compared to when the birds are being normally vigilant, such as flying to and from a roost site. so flocks exhibiting a wide variety of **behavoiurs,** especially those common close to airfields, should be **filmed** for modeling. The reaction of birds to approaching aircraft has been little studied. but it is possible that they have avoidance behaviours which will decrease their likely hood of being struck

This behaviour may be dependent upon their perception of the threat posed by approaching aircraft, Cuthiil and Guilford (1990) found that the perception by Starlings of the risk from obstacles placed in the way of their food source was dependent upon hunger level. The reaction of birds to aircraft may depend upon how they perceive the threat at the time. This clearly has implications for aerodrome bird control but it also means that the behaviour and structure of flocks filmed may not be the same as that of flocks in the vicinity of aircraft. Filming of flocks on or close to airfields will therefore be required.

Conclusion

Clearly a great many more flocks have to be modeled. If data obtained by this method are to be used to formulate new impact tests. sufficient species have to be studied so that we can establish whether the wingspan/flock density relationship is valid, or if it is not, to determine which representative species at each test weight category must be modeled Within each species, it is necessary to collect data on flocks containing a wide range of bird numbers to see whether this affects nearest neighbour distance and overall flock shape. Similarly the effect of different behaviours on flock structure should be investigated. preferably close to airfields. The size of flocks likely to be struck by aircraft should be established by field observations or literature study.

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